



LEHIGH
UNIVERSITY

Institute for Data,
Intelligent Systems, and
Computation (I-DISC)



Robot Learning Workshop

Poster Session

& Reception

5:00-6:30pm

Monday, October 14 | Governor's Lobby & Suite | Iacocca Hall

26 poster presentations by faculty and students from the following institutions

Columbia University

Lafayette College

Lehigh University

New York University

Northeastern University

Stonybrook University, NY

University of California, Riverside

University of Maryland

University of Pennsylvania

University of Texas at Austin

University of Virginia

Worcester Polytechnic Institute

Poster titles; presenters, authors and abstracts attached | Each poster is numbered for quick reference.

Robot Learning Workshop | Poster Session

(presenters in bold)

1. CO-ROBOTS AND MACHINE LEARNING FOR PERSONALIZED FEEDBACK

Authors: **Christian Lopez**, **Computer Science & Mechanical Engineering, Lafayette College**; Conrad Tucker, Mechanical Engineering & Machine Learning, Carnegie Mellon University

Abstract: In traditional learning environments, instructors are able to provide personalized assistance and real-time feedback to students based on the facial or body cues they project, as well as their performance on a task. However, this personalized assistance might be challenging to achieve in environments where the student to instructor ratio is high (e.g., engineering lab environments). As a result of these challenges, a machine learning method for predicting students' performance prior to the start of a task is presented. The method employs students' facial expressions captured while reading the instruction of a task to predict their performance. A case study involving 40 students performing tasks in an engineering lab environment is used to validate the method. Furthermore, this work explores how this method could be implemented in a Collaborative-Robot (Co-robot) system to aid students towards the successful completion of an assignment by providing students with real-time feedback. The Co-robot system could provide instructions to a student on how to perform a task while capturing the student's facial expression that serves as input for the proposed machine learning model. Subsequently, based on the model's prediction, the Co-robot system could potentially provide a personalized intervention or feedback to students (e.g., detailed instructions) with the intention of avoiding students' disengagement after failure. This personalized intervention and real-time feedback have the potential to improve students' performance and learning, as well as to improve the retention of students in STEM fields

2. ORDERING IN GRAPHICAL MODELS AND MACHINE LEARNING

Authors: **Yicheng Chen**, **Lehigh University**; Rick S. Blum Lehigh University; Brian M. Sadler, Army Research Laboratory

Abstract: Signal detection is one application for which dedicated sensor networks have been proposed. Joint signal processing and communication design of such networks has been of great interest recently. We consider new approaches where transmissions can be ordered and halted when sufficient evidence is accumulated. We demonstrate that these approaches require, on average, fewer sensor transmissions and that the savings can be significant in cases of interest. We describe a highly efficient approach which saves transmissions over either the optimum unconstrained energy approach or censoring while achieving the same error probability as these approaches.

3. TOPOLOGICAL APPROXIMATE DYNAMIC PROGRAMMING UNDER TEMPORAL LOGIC CONSTRAINTS

Authors: **Lening Li**, **Worcester Polytechnic Institute**; Jie Fu, Worcester Polytechnic Institute

Abstract: In this work, we develop a tadp method for stochastic systems modeled as mdps to maximize the probability of satisfying high-level system specifications expressed in a subclass of ltl --- sctl . Our proposed method includes two steps: First, we decompose the planning problem into a sequence of sub-problems based on the topological property of the task automaton which is translated from a sctl specification. Second, we extend a model-free approximate dynamic programming method to solve value functions, one for each state in the task automaton, in an order reverse to the causal dependency. Particularly, we show that the run-time of the tadp does not grow exponentially with the size of

specifications. The correctness and efficiency of the algorithm are demonstrated using a robotic motion planning example.

4. **OPTIMIZING DEEP NEURAL NETWORKS WITH LOCAL SEARCH**

Authors: **Ahmed Aly, University of Virginia**; Gianluca Guadagni University of Virginia; Joanne B. Dugan University of Virginia

Abstract: Deep Neural Networks have received a great deal of attention in the past few years. Applications of Deep Learning broached areas of different domains such as Reinforcement Learning, Algorithmic Trading and Computer Vision. Despite their popularity and success, training neural networks can be a challenging process. This paper presents a study on derivative-free, single-candidate optimization of neural networks using Local Search (LS). Experiments were conducted using a setup that is both suitable for an introduction of the algorithm and representative of modern deep learning tasks, based on the FashionMNIST dataset. Training of a 5-Million parameter CNN was done in several scenarios, including Stochastic Gradient Descent (SGD) coupled with Backpropagation (BP) for comparison. Results reveal that although LS was not competitive in terms of convergence speed, it was actually able to converge to a lower loss than SGD. In addition, LS trained the CNN using Accuracy rather than Loss as a learning signal, though to a lower performance. In conclusion, LS presents a viable alternative in cases where SGD fails or is not suitable. The simplicity of LS can make it attractive to non-experts who would want to try neural nets for the first-time or on novel, non-differentiable tasks. The presence of a derivative-free single-candidate optimization algorithm for neural networks holds great promise for use in Robot Learning.

5. **ROBUST MODEL PREDICTIVE SHIELDING FOR SAFE REINFORCEMENT LEARNING WITH STOCHASTIC DYNAMICS**

Authors: **Shuo Li, University of Pennsylvania**; Osbert Bastani, University of Pennsylvania

Abstract: This paper proposes a framework for safe reinforcement learning that can handle stochastic nonlinear dynamical systems. We focus on the setting where the nominal dynamics are known, and are subject to additive stochastic disturbances with known distribution. Our goal is to ensure the safety of a control policy trained using reinforcement learning, e.g., in a simulated environment. We build on the idea of model predictive shielding (MPS), where a backup controller is used to override the learned policy as needed to ensure safety. The key challenge is how to compute a backup policy in the context of stochastic dynamics. We propose to use a tube-based robust NMPC controller as the backup controller. We estimate the tubes using sampled trajectories, leveraging ideas from statistical learning theory to obtain high-probability guarantees. We empirically demonstrate that our approach can ensure safety in stochastic systems, including cart-pole and a non-holonomic particle with random obstacles.

6. **VISION-BASED DOCKING AND ASSEMBLY FRO MODULAR QUADROTOR SWARM STRUCTURES**

Authors: **Yehonathan Litman**, Stony Brook University; David Saldaña, Lehigh University; Vijay Kumar, University of Pennsylvania

Abstract: Modular aerial swarms offer promising advantages due to their ability to perform tasks unsuitable for individual quadrotors. Plenty of work has been done in developing proper control algorithms for modular swarms, but little has been done in regards to assembly and control for quadrotors in outdoor environments

with only onboard sensors. In this paper, we present both a docking and assembly methodologies aimed at constructing modular aerial formations with quadrotors sporting only a single camera and an Inertial Measurement Unit (IMU). With the usage of a realistic simulation environment, we verify that our control algorithm for docking performs well under extraneous forces. In addition, we derive an algorithm that addresses the modules' limited sensing capabilities in order to assemble a wide variety of structures. We also prove that our assembly algorithm's time complexity is low, showing that it has potential in being used on large scale modular robotic systems.

7. **MAMPS: SAFE MULTI-AGENT REINFORCEMENT LEARNING VIA MODEL PREDICTIVE SHIELDING**

Authors: **Wenbo Zhang, GRASP Lab, University of Pennsylvania**; Osbert Bastani, PRECISE Lab, Department of Computer and Information Science, University of Pennsylvania

Abstract: Reinforcement learning is a promising approach to learning control policies for performing complex multi-agent robotics tasks. However, a policy learned in simulation often fails to guarantee even simple safety properties such as obstacle avoidance. To ensure safety, we propose multi-agent model predictive shielding (MAMPS), an algorithm that provably guarantees safety for an arbitrary learned policy. In particular, it operates by using the learned policy as often as possible, but instead uses a backup policy in cases where it cannot guarantee the safety of the learned policy. Using a multi-agent simulation environment, we show how MAMPS can achieve good performance while ensuring safety.

8. **SELF-RECONFIGURATION IN RESPONSE TO FAULTS IN MODULAR AERIAL SYSTEMS**

Authors: **Neeraj Gandhi, University of Pennsylvania**; David Saldaña, Lehigh University; Vijay Kumar, University of Pennsylvania; Linh Thi Xuan Phan, University of Pennsylvania

Abstract: We present a fault-tolerance technique for a modular flying platform to mitigate the impact of faults through self-reconfiguration. In this technique, the modular system adapts its configuration in response to rotor failures to ensure mission continuation and efficient resource utilization. We introduce a mixed integer linear program to determine an optimal module allocation in the structure based on rotor faults and desired trajectories. We further propose an efficient dynamic programming algorithm that minimizes the number of disassembly and reassembly steps needed for reconfiguration. Evaluation results show that our technique can substantially increase the robustness of the system while utilizing resources efficiently, and that it can scale well with the number of modules.

9. **PERMUTATION INVARIANT REPRESENTATIONS FOR GRAPH CONVOLUTIONAL NETWORKS**

Authors: **Naveed Haghani, University of Maryland**; Radu Balan, University of Maryland; Maneesh Singh, Verisk

Abstract: We address the problem of graph classification and graph regression using graph convolutional neural networks. Many graph neural network algorithms can be abstracted as a series of message passing functions between the nodes, ultimately producing a set of latent features for each node. Processing these latent features to produce a single estimate over the entire graph is dependent on how the nodes are ordered in the graph's representation. We propose a permutation invariant mapping that produces graph representations that are invariant to any ordering of the nodes. This mapping can serve as a pivotal piece in leveraging graph convolutional networks for graph classification and graph regression problems.

10. **TASK-ORIENTED ACTIVE PERCEPTION AND PLANNING IN ENVIRONMENTS WITH PARTIALLY KNOWN SEMANTICS**

Authors: **Mahsa Ghasemi**, University of Texas at Austin; Arinc Bulgur, University of Texas at Austin; Ufuk Topcu, University of Texas at Austin

Abstract: In a variety of real world problems, the available information, obtained by sensory measurements, regarding variables of interest is either partial or uncertain in nature. In such settings, a robotic agent may keep a probabilistic representation of the variables according to the data seen thus far, and update it as new data arrives. The evolution of robot's knowledge about its surroundings calls for a planning strategy that evolves as well. We consider agents that are assigned a temporal logic task in environments whose semantic representation is only partially known. We represent the semantics of the environment with a set of state properties for which the agent holds a probabilistic belief. The goal is to design a policy for the agent that realizes the task with high probability. We develop a planning strategy that provides probabilistic guarantees of task success by taking the semantic uncertainties into account. Furthermore, as new data arrives, the planner is able to adapt the policy accordingly. We evaluate the proposed method on various finite- horizon tasks in a robotic navigation setting.

11. **RIP: GRAPH-BASED INTERACTION-AWARE TRAJECTORY PREDICTION**

Authors: Xin Li, Lehigh University; **Xiaowen Ying**, Lehigh University; Mooi Choo Chuah, Lehigh University

Abstract: Nowadays, autonomous driving cars have become commercially available. However, the safety of self-driving car is still a challenging problem that has not been well studied. Motion prediction is one of the core functions of an autonomous driving car. In this paper, we propose a novel scheme called GRIP which is designed to predict trajectories for traffic agents around an autonomous car efficiently. GRIP uses a graph to represent the interactions of close objects, applies several graph convolutional blocks to extract features, and subsequently uses an encoder-decoder long short-term memory (LSTM) model to make predictions. The experimental results on two well-known public datasets show that our proposed model improves the prediction accuracy of the state-of-the-art solution by 30%. The prediction error of GRIP is one meter shorter than existing schemes. Such an improvement can help autonomous driving cars avoid many traffic accidents. In addition, the proposed GRIP runs 5x faster than the state-of-the-art schemes.

12. **SYNTHESIS OF A TIME-VARYING COMMUNICATION NETWORK BY ROBOT TEAMS WITH INFORMATION PROPAGATION GUARANTEES**

Authors: **Xi Yu**, University of Pennsylvania; M. Ani Hsieh, University of Pennsylvania

Abstract: We present a distributed control and coordination strategy to enable a swarm of mobile robots to form an intermittently connected communication network while monitoring an environment. In particular, we consider the scenario where robots are tasked to patrol a collection of perimeters within a workspace and are only able to communicate with one another when they move into each other's communication range as they move along their respective perimeters. We show how intermittent connectivity can be achieved as each robot synchronizes their speed with robots moving along neighboring perimeters. By ensuring future rendezvous between robot pairs, the team forms a time-varying communication network where information can be successfully transmitted between any pair of robots within some finite period of time. We show how the proposed strategy guarantees a τ -connected network for some finite $\tau > 0$ and provide bounds on the time needed to propagate information throughout the network. Simulations are presented to show the feasibility of our strategy and validity of our approach.

13. **DEVELOPMENT OF A NONLINEAR MODEL PREDICTIVE CONTROL FOR A QUADCOPTER AND ITS VALIDATION IN THE HARDWARE-IN-THE-LOOP SIMULATION ENVIRONMENT**

Authors: **David Tanous, Lehigh University**; Titilayo Fasoro, Illinois Institute of Technology; Dr. Dae Young Lee, Iowa State University. [This research is currently ongoing and was part of a summer NSF REU]

Abstract: Hardware-in-the-loop simulation (HILS) is a tool for validating controller design and provides a robust and safe method to simulate UAV flight before actual testing. It allows us to detect issues and refine our algorithms quickly and cheaply by simulating our system with a controller on the desktop. It is a useful tool for designing control algorithms, which are necessary for more practical drone applications in industry and research. Such applications have not come to fruition yet due to the challenging control requirements posed by the quadcopter. In this paper, we present a virtual test bed for HILS to validate the developed nonlinear model predictive control (NMPC). We test a geometric mechanics-based flight controller using Simulink, which allows us to track the flight dynamics with SO3. Our custom flight controller can switch between position/velocity and attitude tracking modes. Our model-based design allows for a smooth flight trajectory when switching between flight modes. We track the position and attitude and error functions associated with our model to determine its validity as a robust flight controller. Our findings indicate that the NMPC based on geometric mechanics provides a robust performance to handle constraint maneuvers of the quadcopter such as collision avoidance. Quadcopters with consistent object detecting and evading capabilities are essential for commercial use in the future.

14. **LEARNING YOUR WAY WITHOUT MAP OR COMPASS: PANORAMIC TARGET DRIVEN VISUAL NAVIGATION.**

Authors: **David Watkins-Valls*¹, Jingxi Xu*¹**, Nicholas Waytowich ², and Peter Allen ¹ **Department of Computer Science, Columbia University**, New York, NY, USA. ² U.S. Army Research Laboratory, Baltimore, MD, USA.

Abstract: We present a robot navigation system that uses an imitation learning framework to successfully navigate in complex environments. Our framework takes a pre-built 3D scan of a real environment and trains an agent from pre-generated expert trajectories to navigate to any position given a panoramic view of the goal and the current visual input without relying on map, compass, odometry, GPS or relative position of the target at runtime. Our end-to-end trained agent uses RGB and depth (RGBD) information and can handle large environments (up to 1031m²) across multiple rooms (up to 40) and generalizes to unseen targets. We show that when compared to several baselines using deep reinforcement learning and RGBD SLAM, our method (1) requires fewer training examples and less training time, (2) reaches the goal location with higher accuracy, (3) produces better solutions with shorter paths for long-range navigation tasks, and (4) generalizes to unseen environments given an RGBD map of the environment.

15. **MULTI-AGENT IMAGE CLASSIFICATION VIA REINFORCEMENT LEARNING**

Authors: Hossein K. Mousavi, Mohammadreza Nazari, Martin Takác, and Nader Motee, Lehigh University, **Guangyi Liu, Lehigh University**

Abstract: We investigate a classification problem using multiple mobile agents that are capable of collecting (partial) pose-dependent observations of an unknown environment. The objective is to classify an image (e.g. map of a large area) over a finite time horizon. We propose a network architecture on how agents should form a local belief, take local actions, extract relevant features and specification from their raw partial observations. Agents are allowed to exchange information with their neighboring agents and run a decentralized consensus protocol to update their own beliefs. It is shown how reinforcement learning techniques can be utilized to

achieve decentralized implementation of the classification problem. Our experimental results on MNIST handwritten digit dataset demonstrates the effectiveness of our proposed framework.

16. **SWARM OF DECENTRALIZED ROBOTS EXPLORATION AND NAVIGATION IN AN UNKNOWN ENVIRONMENT WITH LIMITED RESOURCES AND DIRECTIONAL SENSORS**

Authors: **Mohammad Saleh Teymouri, Department of Mechanical Engineering and Mechanics, Lehigh University**; Subhrajit Bhattacharya Department of Mechanical Engineering and Mechanics, Lehigh University

Abstract: Topological modeling and algebraic hole-detection of an unknown, GPS-denied environment are addressed by using swarm of decentralized robots with limited resources and directional sensors. Adopting concepts like “Simplicial Complexes” and “Landmark Complexes” facilitated the multi-thread implementation in C++ due to the optimum amount of information that need to be shared with other robots, by creating a metric-free model of the environment.

17. **DEEP GOAL-CONDITIONED VIDEO PREDICTION AND IMITATION LEARNING**

Authors: **Oleh Rybkin***¹, Karl Pertsch*², Frederik Ebert*³, Chelsea Finn⁴, Dinesh Jayaraman⁵, Sergey Levine³ ¹ **University of Pennsylvania** ² University of Southern California ³ University of California, Berkeley ⁴ Stanford University ⁵ Facebook AI

Abstract: The ability to predict and plan into the future is fundamental for agents acting in the world. When planning to solve a task, it is natural to consider predictions towards a goal. Prior work on visual model predictive control largely focuses on prediction models that only observe frames from the beginning of the video. Goal-Conditioned Prediction (GCP) instead treats videos as start-goal transformations, making prediction easier by conditioning on the more informative context provided by the first and final frames. Not only do existing neural network approaches for forward prediction synthesize better and longer videos when modified to become goal-conditioned, but GCP models can also utilize structures that are not linear in time, to accomplish hierarchical prediction. To this end, we study both sequential GCP models and novel tree-structured GCP models that generate frames recursively, splitting the video iteratively into finer and finer segments delineated by subgoals. In experiments across simulated and real datasets, our GCP methods generate high-quality sequences over long horizons. Tree-structured GCPs are also substantially easier to parallelize than auto-regressive GCPs, making training and inference very efficient, and allowing the model to train on sequences that are thousands of frames in length. Finally, we demonstrate the ability of GCP to construct visual plans learned through imitation without access to expert actions.

18. **A TOPOLOGICAL APPROACH TO WORKSPACE AND MOTION PLANNING FOR A CABLE-CONTROLLED ROBOT IN CLUTTERED ENVIRONMENTS**

Authors: **Xiaolong Wang, Lehigh University**; Subhrajit Bhattacharya, Lehigh University

Abstract: There is a rising demand for multiple-cable controlled robots in stadiums or warehouses due to its low cost, longer operation time, and higher safety standards. In a cluttered environment, the cables can wrap around obstacles, but careful choices need to be made for the initial cable configurations to ensure that the workspace of the robot is optimized. The presence of cables makes it imperative to consider the homotopy classes of the cables both in the design and motion planning problems. In this project, we study the problem of workspace planning for multiple-cable controlled robots in an environment with polygonal obstacles. This project's goal is to establish a relationship between the boundary of the workspace and cable configurations of such robots and solve related optimization and motion planning problems. We first analyze the conditions

under which a configuration of a cable- controlled robot can be considered valid, discuss the relationship between cable configuration, the robot's workspace, and its motion state, and using graph search-based motion planning in h-augmented graph perform workspace optimization and compute optimal paths for the robot. We demonstrated the algorithms in simulations.

19. MULTI-AGENT PURSUIT-EVASION UNDER UNCERTAINTIES WITH REDUNDANT ROBOT ASSIGNMENTS

Authors: **Leiming Zhang, Department of Mechanical Engineering and Mechanics, Leigh University;** Amanda Prorok, Department of Computer Science and Technology, Cambridge University; Subhrajit Bhattacharya, Department of Mechanical Engineering and Mechanics, Leigh University.

Abstract: We consider a pursuit-evasion problem with a heterogeneous team of multiple pursuers and multiple evaders. The pursuers (robots), using only noisy on-board sensors, can make a probabilistic estimation of positions of multiple moving evaders based on sensor measurements of signals emitted by the evaders. The evaders being aware of the environment and the position of all pursuers follow a strategy to actively avoid being intercepted. We model the evaders' motion as a time-varying Markov process, and along with stochastic measurements, the pursuers use Markov Localization to update the probability distribution of the evaders. A search-based motion planning strategy is developed that intrinsically takes the probability distribution of the evaders into account. Pursuers are assigned using an assignment algorithm that takes redundancy into account, such that the estimated net time to capture the evaders is minimized. Our experimental evaluation shows that the redundant assignment algorithm performs better than an alternative nearest-neighbor based assignment algorithm.

20. REINFORCEMENT LEARNING FOR SEMI-SUPERVISED DOMAIN ADAPTATION

Authors: **Youshan Zhang, Lehigh University;** Hui Ye, Lehigh University

Abstract: Domain adaptation is a widely used method for solving the domain shift problem in image recognition. There have been many pre-trained neural networks for feature extraction. However, limited work has discussed how to select the best feature instance for both the source and target domain. In this paper, we are the first to apply reinforcement learning for the feature instance selection in domain adaptation. Specifically, we employ Q-learning to learn policies for an agent to make feature selection decisions by approximating the action-value function. By selecting the best feature, we propose a distribution alignment method to improve the prediction results. Extensive experiments demonstrate that our proposed method outperforms the state-of-the-art.

21. A STATISTICAL LEARNING-BASED ALGORITHM FOR TOPOLOGY VERIFICATION IN NATURAL GAS NETWORKS BASED ON NOISY SENSOR MEASUREMENTS

Authors: **Zisheng Wang, Lehigh University;** Rick Blum, Lehigh University

Abstract: Accurate knowledge of natural gas network topology is critical for the proper operation of natural gas networks. Failures, physical attacks, and cyber attacks can cause the actual natural gas network topology to differ from what the operator believes to be present. Incorrect topology information misleads the operator to apply inappropriate control causing damage and lack of gas supply. Several methods for verifying the topology have been suggested in the literature for electrical power distribution networks, but we are not aware of any publications for natural gas networks. In this paper, we develop a useful topology verification algorithm for natural gas networks based on modifying a general known statistics-based approach to eliminate serious limitations for this application while maintaining good performance. We prove that the new algorithm is

equivalent to the original statistics-based approach for a sufficiently large number of sensor observations. We provide new closed-form expressions for the asymptotic performance that are shown to be accurate for the typical number of sensor observations required to achieve reliable performance.

22. DISTRIBUTED CONTROL SYSTEM IN LEGGED ROBOT APPLICATION

Authors: **Pravin Dangol**, Northeastern University; Alireza Ramezani, and Milad Siami, Northeastern University, Boston, MA

Abstract: Raibert's hopping robots and Boston Dynamic's BigDog are amongst the most successful examples of legged robots, as they can hop or trot robustly even in the presence of significant unplanned disturbances. Other than these successful examples, a large number of humanoid robots have also been introduced. Honda's ASIMO, Samsung's Mahru III, ETH StarlETH, MIT's Chittah Robot are capable of walking, running, dancing and going up and down stairs, and the Yobotics-IHMC biped can recover from pushes. Despite these achievements, even biological locomotor systems such as humans and animals whose natural and dynamic gaits has remained unmatched and outperform our robots cannot recover from severe external perturbations such as a powerful push on someone's back. In this work, we investigate the performance analysis and synthesis of distributed control systems (DCS) for a morpho-functional machine capable of morphing from legged to aerial locomotion. Platforms like this that combine aerial and legged modality in a single platform can provide rich and challenging dynamics and control problems. The thrusters add to the array of control inputs in the system (i.e., adds to redundancy and leads to over actuation) which can be beneficial from a practical standpoint and challenging from a feedback design standpoint. Over actuation demands an efficient allocation of control inputs and, on the other hand, can safeguard robustness by providing more resources. Given the increasingly high-dimensional nature of problems involving the interconnection of several dynamic subsystems with sensors and actuators, it is important to be able to estimate and control the state of the overall complex system fast and in a distributed fashion with provable performance guarantees. Using distributed model predictive control (DMPC) law, we guarantee feasibility, near-optimality, and robustness of the robotic system.

23. GRAPH TOPOLOGY LEARNING AND SIGNAL RECOVERY VIA BAYESIAN INFERENCE

Authors: Mahmoud Ramezani-Mayiami, University of Agder, Norway; **Mohammad Hajimirsadeghi**, **Lehigh/Princeton Universities**; Karl Skretting, University of Stavanger, Norway; Rick S. Blum, Lehigh University, USA; H. Vincent Poor, Princeton University, USA

Abstract: the estimation of a meaningful affinity graph has become a crucial task for representation of data, since the underlying structure is not readily available in many applications. In this paper, a topology inference framework, called Bayesian Topology Learning, is proposed to estimate the underlying graph topology from a given set of noisy measurements of signals. It is assumed that the graph signals are generated from Gaussian Markov Random Field processes. First, using a factor analysis model, the noisy measured data is represented in a latent space and its posterior probability density function is found. Thereafter, by utilizing the minimum mean square error estimator and the Expectation Maximization (EM) procedure, a filter is proposed to recover the signal from noisy measurements and an optimization problem is formulated to estimate the underlying graph topology. The experimental results show that the proposed method has better performance when compared to the current state-of-the-art algorithms with different performance measures.

24. VISION-BASED COOPERATIVE TRANSPORTATION WITH MAVS

Authors: **Guanrui Li, New York University**; Giuseppe Loianno, New York University

Abstract: This addresses the cooperative transportation problem with multiple autonomous aerial vehicles using rigid or cable connections. The dynamics and control theory of the system has been well studied. However, there are still several challenges to be taken into account in the perception-action loop problem. There is a strict cross-coupling between control, perception, mechanics, and dynamics that need to be taken into account. We plan to approach this problem by developing a light-weight real-time supervised deep learning method that could combine object detection and 6DOF pose estimation together in a single network. Using the pose estimation output of the network as the feedback of the developed controller, we plan to control the payload tightly coupling the received feedback with onboard state estimation of the robots, system mechanics, and dynamics. This will contribute to pushing the flight agility and tracking performances with envelopes that consider large excursions from hovering point.

25. CARLEMAN STATE FEEDBACK CONTROL DESIGN OF A CLASS OF NONLINEAR CONTROL SYSTEMS

Authors: **Arash Amini, Lehigh University**; Qiyu Sun, Nader Motee, Lehigh University

Abstract: We consider optimal feedback control design for nonlinear control systems with polynomial right-hand sides. The control objective is to minimize a quadratic cost functional over all state feedback control laws with polynomial structure subject to dynamics of the system. First, we utilize ideas from Carleman linearization to lift a given finite-dimensional nonlinear system into an infinite-dimensional linear system. Finite-order truncations of the resulting infinite-dimensional linear system are investigated and connections between (local) stability properties of the original nonlinear system and its finite-order truncations are established. We show that the optimal feedback control design can be approximated and cast as an optimization problem with bilinear matrix equation constraints. Through several simulations, we show that this approximate method can be efficiently implemented using the Alternating Direction Method of Multipliers (ADMM) methods.

26. ACCURACY PREVENTS ROBUSTNESS IN DATA-DRIVEN ALGORITHMS

Authors: **Abed AlRahman Al Makdah, Department of Electrical & Computer Engineering, University of California, Riverside**; Vaibhav Katewa, and Fabio Pasqualetti, Department of Mechanical Engineering at the University of California, Riverside

Abstract: In this work, we take an important step towards formally proving the existence of a fundamental trade-off between accuracy and robustness for data-driven algorithms. In particular, we formally show that, in a quest to optimize their accuracy, data-driven algorithms – including those based on machine learning techniques – inevitably become more sensitive to data variations (accidentally or maliciously). We rigorously study this tradeoff in binary classification problem settings, as well as, in perception-based control problems, in which, control decisions rely solely on data-driven, and often incompletely trained, perception maps.